Introducing Automated Obstacle Detection to British Level Crossings

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Abstract

This paper discusses the implementation of automated obstacle detection to British level crossings to improve safety, efficiency and reduce costs and analyses how successful this could be. There are over 6000 level crossings in Britain and they are the largest single risk to the railways; one method to improve their safety is by introducing automated obstacle detection. Over the last ten years there have been, on average, 9 deaths a year at level crossings (Rail Safety and Standards Board, 2016) (excluding suicides), making them a high priority for Network Rail to improve. Obstacle detection wouldn't just help improve the safety of level crossings, but it could also reduce the costs associated with level crossing signallers and operators and would lower the waiting times for road vehicles and pedestrians. With research also being done into the future possibility of introducing autonomous trains to the British railways, the combination of this and the obstacle detection system proposed could see a large improvement in safety across the level crossings.

1. Introduction

Each year, there is an average of 50 accidental deaths on British railways (Office of Rail and Road, 2016), 9 of which occur at level crossings. A level crossing is a place at which a footpath or road cross a railway track. "Collisions at level crossings are the largest single cause of train accident risk" (Rail Safety and Standards Board, 2016) and should therefore be a main area to focus on for improving the safety of the railway as a whole.

Introducing automated obstacle detection is a way in which safety could be improved at certain level crossings, due to the elimination of human error. Having automated obstacle detection isn't just about knowing whether or not there is an object on the crossing, it is also about communicating a signal to the train to indicate the action that should take place. Then, depending on what response the detection has, having the technology in place for the train to know how to react under different scenarios.

The addition of obstacle detection wouldn't just improve safety on the railway for pedestrians, vehicle users and train passengers; it could also reduce the costs associated with the need for level crossing

signallers and operators. There is also the potential for improved efficiency because of the increased train speeds and a reduction in waiting times for pedestrians and vehicles.
Deciding which level crossings should have automated obstacle detection can be done by analysing the various types of level crossings, the risk associated with using them, how often they're used and any incidents, which may have happened in the past.
The risk associated with using a level crossing has been gradually declining over the last 10 years. However, despite these recent trends in level crossing safety, the potential for a single catastrophic incident that would skew the figures remains. This could be avoided with the introduction of obstacle detection.
In addition to automated obstacle detection, autonomous trains are also a very real future possibility that could come to the British railways. Therefore, it is important to be able to incorporate any final design of level crossing obstacle detection, with the possibility that it may need to be used with autonomous trains too.
The various stages to complete the study were; to decide which crossings should be upgraded, which barriers would be most suitable, what method of obstacle detection would be most effective and the calculation of timings for the closure sequence of these level crossings.

2. State of practice on current solutions

2.1 Current Level Crossings

There are two types of level crossings in Britain and they are put into two separate categories, active and passive crossings. An active crossing is one that shows the user (pedestrian or vehicle user) that a train is approaching by the closure of the crossing and with audible alarms and warning lights. A passive crossing doesn't have any features to show that there is train approaching to the user and they are responsible for deciding whether or not it is safe to use the crossing. There are sufficient signs and instructions in place to demonstrate how to use passive crossings. These two types of level crossings are then divided into various sub-categories, each of these sub-categories have distinct characteristics.

2.1.1. Passive Crossings

User Worked Crossing (UWC/ UWC-T):
This type of level crossing is usually a gate which either a vehicle user or pedestrian must operate in order to get through the level crossing. There are two types of user worked crossings; with and without a telephone. The telephones are usually in place where there is poor visibility and it is difficult for a user to determine whether or not it is safe to cross. There are also multiple signs in place giving the user instructions on how to operate the crossing. The telephones are connected to a signaller who must give permission for the user to cross and then the user must also let the signaller know when the track is clear on the other side. There is a speed restriction of 125mph for trains at these types of crossings in Britain.

Open Crossing (OC):
An open crossing only has signs to warn drivers to come to a stop before passing these level crossings because the area between the road and the rail is completely open. Open crossings are usually located on very quiet roads and in order for the vehicle users to pass safely, good visibility is a necessity for

this crossing. Trains must slow down to a maximum speed of 10mph before crossing and some even stop completely before the level crossing to minimise the risk of a collision.

Footpath Crossing (FP):
These crossings are designed for the use of pedestrians and not vehicle users; they often have stiles or gates in place to reduce usage. There are no warning signals given to the crossing user with most of these crossings, however, in some cases where there is low sighting time, a “whistle” board may be put in place to make the train driver sound the horn to alert anyone wishing to cross that it isn’t safe to do so. It is solely the crossing user’s responsibility for ensuring that it is safe to cross before doing so. Similarly to user worked crossings, there are various signs in place to display to users the dangers and instructions of using the crossings. The maximum train line speed for a footpath crossing is 125mph.

2.1.2. Active Crossings
There are two different types of active crossings; manual and automatic. A manual crossing has a signaller and/or crossing keeper to operate the level crossing. An automatic crossing is activated from an approaching train reaching a “strike-in” point and doesn’t rely on humans to operate them. A strike-in point is the distance back from a level crossing a train is which then initiates the closure sequence of the crossing.

Manually Controlled Gate (MCG):
These crossings have gates that are operated by a crossing keeper or manually by a signaller. At these crossings the usual position at which the gates are left is open to road traffic; this is usually done on busier roads though. On quieter roads it is often common practice for the gates to remain closed to the public and only opened by a crossing keeper after getting confirmation of no trains approaching the crossing. The maximum line speed at manually controlled gates is 125mph.

Manually Controlled Barrier (MCB):
These crossings are very similar to manually controlled gate crossings as they are controlled by a signaller or crossing keeper. They have full barriers that extend across the width of the road and warning lights and audible sounds are also incorporated within the design of the crossing to let pedestrians know of any approaching trains. After the activation sequence of the level crossing starts, there are amber warning lights and an audible warning for approximately 3 seconds. This is then followed by red flashing lights for 6 seconds, after which, the barriers close. Manually controlled barriers have either barriers that cover the width of the road on both sides of the crossing or 2 half barriers on both sides of the crossing. It takes 6-8 seconds for the barriers to reach the lowered position when the crossing has two full barriers, and takes an additional 6-8 seconds to close the exit barriers for the crossings with two half barriers (Rail Safety & Standards Board, 2006). The level crossing with two half barriers is designed so that vehicles and pedestrians have more time to leave the crossing if they are already on it. After the barriers are fully down the audible warning stops.
The maximum line speed for manually controlled barriers is 125mph. The average closure time of manually controlled barriers is 227 seconds (Rail Safety & Standards Board, 2006). However, if another train is approaching, the barriers will remain down as there would be difficulties raising and lowering the barriers quickly enough to let vehicles and pedestrians through safely.

Manually Controlled Barrier monitored by Closed-Circuit Television (MCB-CCTV):
These are very similar to the manually controlled barrier previously mentioned, except they are monitored with CCTV, which is viewed by a signaller to control the actions of the crossing. The maximum line speed of these crossings is 125mph.

Figure 1. Carlton level crossing (MCB-CCTV)

Automatic Half Barrier Crossing (AHB):
An automatic half barrier crossing has barriers which only extend across the entrance of the road so that the exits are left clear. They are an automatic, active crossing meaning that warning lights and sounds are automatically activated by an approaching train before the closing sequence of the barriers. After the train has passed the level crossing the barriers automatically rise allowing vehicles to pass. The time taken between the activation of the closing sequence and the arrival of the train is a minimum of 27 seconds. This number varies though as only 50% of trains arrive within 50 seconds and 95% of trains arrive within 75 seconds (Rail Safety & Standards Board, 2006). The maximum line speed of an AHB crossing is 100mph (Rail Safety and Standards Board, 2016). The short arrival time of the train is to discourage vehicle users and pedestrians from “zigzagging”. Zigzagging is a term used to describe the action of a driver or pedestrian at an AHB crossing of driving or walking around the entrance barrier and then cutting back across to the correct side of the road to pass the level crossing.

Figure 2. Collingham level crossing (AHB)

Automatic Barrier Locally Monitored (ABCL):
To pedestrians and road vehicles users this appears to be the same as an automatic half barrier crossing, however, the crossing is continuously monitored and the train driver must be sure that the

crossing is clear before arriving. Trains must slow down to a maximum speed of 55mph before reaching the crossing (Rail Safety and Standards Board, 2016).

Automatic Open Crossing Locally Monitored (AOCL):
This type of crossing has no barriers, but has audible warnings and flashing lights telling vehicle users it is unsafe to cross, which are automatically activated when a train is approaching. Road vehicle users and pedestrians should only cross when there are no warning signals being provided. The train driver must slow down to a maximum of 55mph to ensure that the crossing is clear before advancing. If more than one train is approaching the crossing then the lights and warning noise will continue until the second train passes.

Footpath Crossing with Miniature Warning Lights (FP-MWL):
This variation of the typical footpath crossing has similar features. However, the inclusion of red and green lights inform the pedestrian whether or not it is safe to cross. The light remains green until a train approaches the crossing, at which time the light will turn to red and will stay so until the train has passed. The red light could still be showing after a train has gone through which would indicate that another train is approaching and it is still unsafe to pass.

Figure 3. Eaves Lane level crossing (FP-MWL). From left, miniature warning lights showing it is safe to cross, image of level crossing, miniature warning light showing that a train is approaching and it is unsafe to cross.

User Worked Crossing with Miniature Warning Lights (UWC-MWL):
This level crossing has gates or barriers which extend across the whole road or path and the user must operate the crossing themselves before crossing. Similarly to a footpath crossing with miniature warning lights, there are red and green lights indicating to the user when it is safe to cross. There are also signs in place to tell the user how to safely pass the crossing.
Figure 5 shows that the most common types of level crossings in Britain are footpath and user worked crossings. These are both types of passive crossing, so the user has to decide when it is safe to cross. There are also level crossings called station footpath or barrow crossings, which have the same features as a typical footpath crossing so these are included under that category. Also, Network Rail has recently upgraded numerous MCB-CCTV crossings to manually controlled barriers with obstacle detection (MCB-OD) which weren't included in Network Rail's online archive, so aren't in figure 5. These types of crossings will be discussed in a later chapter and a spreadsheet of them can be seen in Appendix A.

Figure 4. Westbrook Lane level crossing (UWC-MWL)

2.1.3. Number of Level Crossings

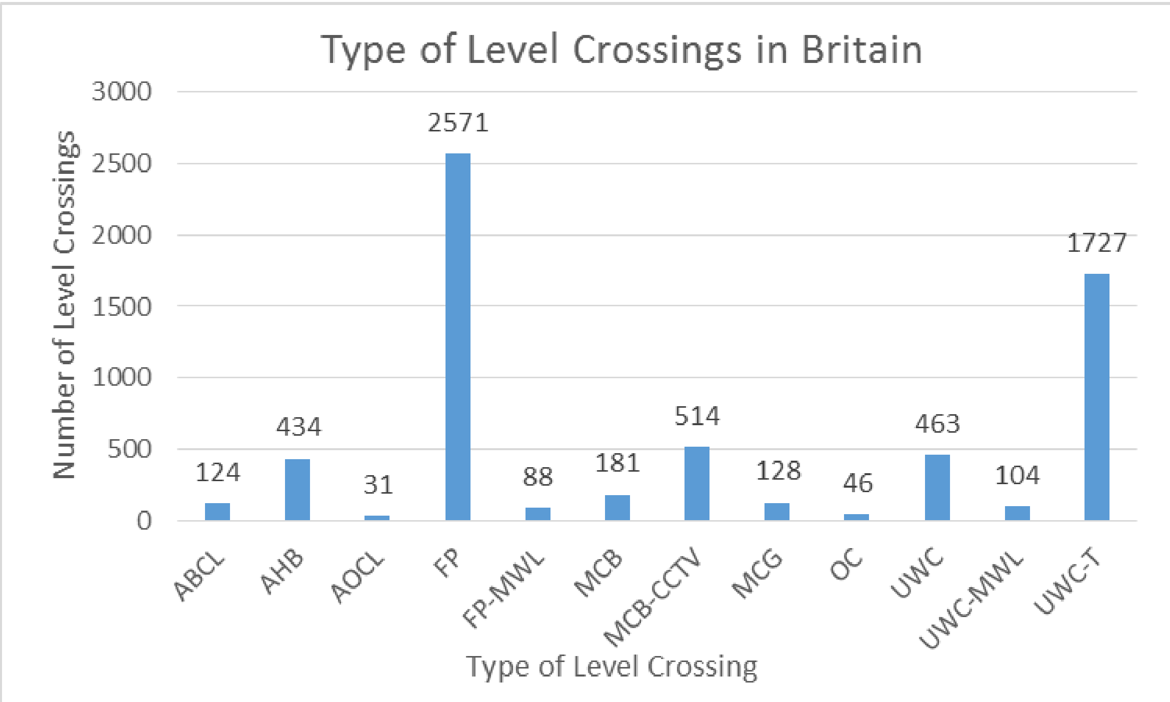

Figure 5. Graph showing the number of different types of level crossing in Britain, the data was collected from Network Rail's online archive (Network Rail, 2017). Some of the level crossings have been closed down which appear in the data so there will be some variation with the actual number of level crossings in Britain and those displayed.

Network Rail is also currently undergoing a project to close down various level crossings to improve the safety of the railway (Network Rail, 2017). Most of the level crossings which have been closed are footpath and user worked crossings. The values taken from the archive were from December 2016 and there are numerous level crossings which are closed but still listed in the archive. An example of this is Barrel Lane level crossing, which is shown in the archive but has closed down as it can be seen in Figure 6.

2.2 Risks

Risk in the context of a level crossing is defined as the likelihood of an incident to take place, and its severity. There are various risk drivers that Network Rail use to determine how safe a level crossing is and whether any action should be taken to improve the safety. The factors that are typically used are:

- Number of pedestrians
- Number of vehicles
- Frequent trains
- Visibility
- Deliberate misuse or user error
- Close to a train station
- Sun Glare
- Poor visibility for approaching vehicles & pedestrians
- Environment

These aspects of a level crossing, along with any past incidents, are the main criteria as to what the risk is with using this level crossing and if anything should be done to improve it.

2.2.1. Fatalities and Weighted Injuries per year

Instead of just using the number of fatalities to determine how many accidents have occurred at a level crossing, Network Rail use "Fatalities and Weighted Injuries per year" (FWI/year). This takes into account major and minor injuries, and also cases of shock and trauma.

<table>
<tr><th>Injury degree</th><th>Weighting</th><th>Number of injuries weighted as equal to a fatality</th></tr>
<tr><td>Fatality</td><td>1</td><td>1</td></tr>
<tr><td>Major Injury</td><td>0.1</td><td>10</td></tr>
<tr><td rowspan="2">Minor Injury (depends on seriousness of injury)</td><td>0.005</td><td>200</td></tr>
<tr><td>0.001</td><td>1000</td></tr>
<tr><td rowspan="2">Shock/ Trauma (depends on seriousness of event to cause it)</td><td>0.005</td><td>200</td></tr>
<tr><td>0.001</td><td>1000</td></tr>
</table>

Table 1. A table taken from a risk analysis report demonstrating how the severity of injuries are weighted against fatalities (Rail Safety and Standards Board, 2016)

Table 1 explains the number of incidents it would take to have the same weighting as a fatality. For example, if there were 10 major injuries in 1 year at level crossings, this would be equivalent to 1FWI/year.

2.2.2. Risk Profiles

There are four main risk profiles stated in Network Rail's Railway Safety Case which categorise how each level crossing accident can occur: (Network Rail, 2005)

- HET-10: A passenger train collides with a road vehicle at a level crossing
- HET-11: A non-passenger train collides with a road vehicle at a level crossing

- HEM-27: A member of the public is struck down by a train at a level crossing
- HEN-44: A member of the public or a road vehicle is either trapped or struck by the level crossing

These risk profiles show that the types of accidents that occur at level crossings vary between different types of crossings. For example, automatic half barrier crossings had an average of 3 FWI/year between 1994 and 2005; this was mainly comprised of HET-10 and HEM-27 incidents which account for 90% of cases at AHB's. In comparison to this, manually controlled barrier crossings with CCTV had an average of 0.7-1 FWI/year, of which 91% were HEM-27 and HEN-44 incidents, implying that vehicles are very rarely involved with accidents at these types of crossing (Rail Safety & Standards Board, 2006).

2.2.3. Individual Risk

This term is used to describe the risk which applies to only the level crossing users. This risk is highest at footpath crossings and user worked crossings. This is because they don't have any warning of incoming trains and it is the pedestrian's responsibility to be the one to determine whether or not it is safe to cross. If there were to be an accident, then the train would remain largely unaffected yet the individual would receive severe injuries. Individual risk is rated from A-M, with A having the highest risk and M having almost none at all.

2.2.4. Collective Risk

This term is used to describe the risk to everyone who is using the crossing: this includes pedestrians, vehicle users, and train drivers and passengers. Collective risk is higher at level crossings that have more vehicles using them.

Table 2. Table with data extracted from the Network Rail archive showing the calculated average risk of different types of level crossing (Network Rail, 2017)

Types of Level Crossing	**Average Risk of Level Crossings**	
	Individual Risk Letter	Collective Risk Number
Automatic Barrier Locally Monitored	**F**	**5**
Automatic Half Barrier	**E**	**4**
Automatic Open Crossing Locally Monitored	**H**	**6**
Footpath Crossing	**D**	**7**
Footpath Crossing with Miniature Warning Lights	**D**	**6**
Manned Barriers	**H**	**5**
Manned Barriers monitored by CCTV	**H**	**5**
Manned Gates	**H**	**7**
Open Crossing	**G**	**6**
User Worked Crossing	**D**	**8**
User Worked Crossing with Miniature Warning Lights	**C**	**5**
User Worked Crossing with Telephone	**C**	**7**

This is because a collision involving a vehicle would be more likely to lead to injuries and potential fatalities for people on the train. The highest collective risk occurs at automatic half barrier crossings, this is primarily because they are heavily used by vehicles and are more likely to be involved in a collision due to misuse by zigzagging. Collective risk is measured on a scale from 1-13, with 1 having the highest risk to everyone and 13 having little to no risk.

Every level crossing has its own individual risk score, and Table 2 shows the average risk calculated from all of the individual scores. The spreadsheet with which these values were calculated can be seen in Appendix B.

2.2.5. Reducing risk

The only true way to have no risk at level crossings is to close them down. Since 2010, Network Rail has been reducing the number of level crossings on the British network to improve safety. A level crossing could be shut down after an extensive risk assessment is carried out. The factors which determine whether it should close include; location, traffic and history of past incidents. In many locations there is still the need to cross a railway though, so simply closing them down isn't a valid solution.

There are multiple alternatives which can be done if a level crossing is closed down; these are diversions, road bridges, stepped footbridges, ramped footbridges, and underpasses (Network Rail, 2017). See Appendix C for a list of the proposed level crossing closures by Network Rail. These safety measures are not excessively costly for the reduction in risk obtained, making this a very desirable option for Network Rail.

On the 10th April 2016, a train collided with a tractor at a user worked crossing after a signaller "lost awareness" and said it was safe to cross (Murphy, 2017). The train was approximately one minute away when the tractor driver was told he could use the crossing. The train accident seriously injured the tractor driver and 4 passengers also suffered minor injuries. The crossing has now been equipped with miniature warning lights to reduce the chance of another collision occurring. Human error will always remain a potential hazard and this is a prime example for why more automated systems should be in place at level crossings.

Lincoln High Street Level Crossing:

One case of reducing risk is the level crossing on Lincoln High Street. Every day, the level crossing is used by approximately 35,000 people and around 140 trains pass through it (Network Rail, 2017). It was originally targeted due to it having the highest case of misuse in the region (Pidluznyj, 2016). Network Rail proposed to put a footbridge (with lifts) over the crossing, in an attempt reduce the misuse caused by pedestrians who would run across the level crossing as the barriers lower. Having the bridge there would allow pedestrians to cross the railway safely while the barriers are down, rather than waiting for a train to pass. The plans for it were accelerated after a woman attempted to run across as the barriers were closing, resulting in her tripping and being badly injured. The footbridge reportedly cost £12 million and opened on the 24th June 2016 (Pidluznyj, 2016).

Since opening, the bridge experienced problems within the first few months. There were reportedly issues with the paving stones coming loose and the lift malfunctioning causing pedestrians to be trapped inside (Barker, 2016). This required a lot of maintenance to get it to a standard which was safe for the public to use, thus increasing costs.

Figure 7. The footbridge over Lincoln High Street level crossing

Witnessing first hand, even now when the footbridge is fully functional and safe to use, some pedestrians still choose to run across when the audible warning sounds to reach the other side, before the barriers close. The bridge is primarily used by pedestrians who reach the level crossing as the barriers have just come down. There are also approximately half of the pedestrians who want to pass, who still wait by the barriers rather than using the bridge, see Appendix D. As a way to reduce people trying to run across the crossing, this method doesn't appear effective.

On the 21st April 2017, an elderly person attempted to pass the crossing after the warning lights and sounds were activated. However, they didn't leave enough time to cross and got pinned to the ground under one of the barriers (Barker, 2017). This demonstrates that people would still rather risk rushing across the level crossing as they are closing, rather than being safe and using the footbridge. Therefore this is clearly an ineffective way to reduce the risk at some level crossings.

2.2.6. Risk Statistics

62% of risk at level crossings is to pedestrians, 92% of pedestrians at risk are members of the public using the crossing and the rest are train passengers who have to use a level crossing to get to the correct platform at a station. 32% of risk is due to vehicle collisions, 91% of this value affects the people in road vehicles and the rest are to train passengers (Rail Safety and Standards Board, 2016).

In the past 50 years, there have only been 3 cases of a catastrophic event happen at a level crossing in Britain (Rail Safety & Standards Board, 2006). These events caused multiple fatalities, including passengers on trains, and all involved a train colliding with a road vehicle. The most recent of these events happened in 2004 near a village called Ufton Nervet. This was caused by a vehicle driver committing suicide by parking on an automatic half barrier crossing. A train collided with the road vehicle causing a derailment that resulted in 7 fatalities (BBC News, 2016).

Automatic half barrier crossings have the greatest number of fatalities and weighted injuries at an average of 3 FWI/year, which is a quarter of the entirety of the risk at all level crossings. (MCB-CCTV in comparison have an average of 0.7-1FWI/year) (Rail Safety & Standards Board, 2006).

Over the past ten years there has been a gradual decline in the number of fatalities that have occurred at level crossings, although there is variation from year to year. The most recent year recorded saw the lowest number of fatalities ever in Britain with only 3. These fatalities occurred at a user worked crossing, footpath crossing and manually controlled barrier with CCTV (Rail Safety and Standards

Board, 2016). For all these fatalities in Figure 8, none of them were passengers on a train and all were pedestrians or vehicle users involved in a collision with a train.

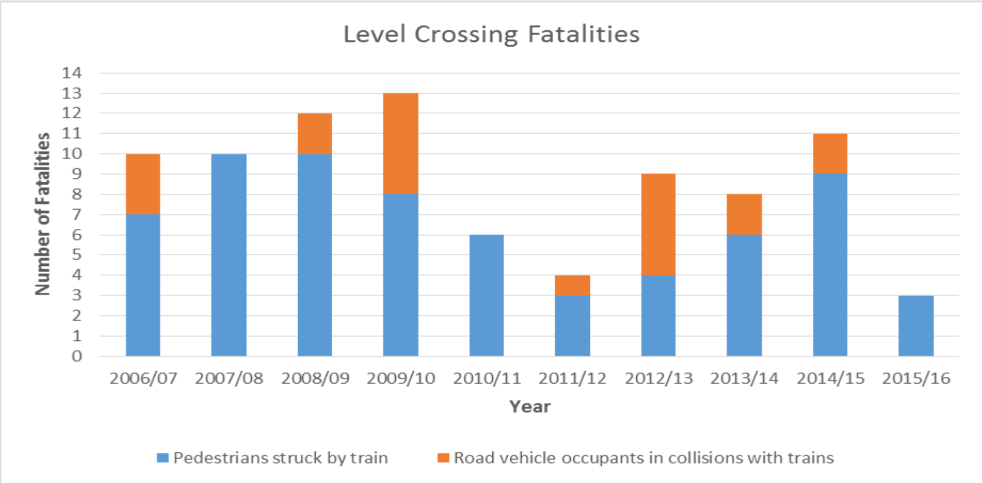

Figure 8. The number of fatalities that have occurred at level crossings over the past 10 years (excluding suicide) (Rail Safety and Standards Board, 2016)

However, like the event, which occurred in Ufton Nervet, it could just take one vehicle to collide with a train to have catastrophic consequences. This is why there is the need for introducing obstacle detection, to improve the safety of level crossings and reduce the risk associated with using them.

2.3 Type of Obstacle Detection

Obstacle detection with an application to level crossings is the ability to determine whether an object is on the crossing, and then be able to send a signal to an approaching train so that it can react accordingly.

Automated obstacle detection would ideally be able to do the following:

- Improve the current safety at level crossings
- Be accurate and not provide false readings
- Not cause delays
- Provide a cost-effective way to save lives
- Work under a wide range of environmental conditions

There are numerous methods of obstacle detection that exist; however, not all of them can be applied to level crossings. The methods of detection which could potentially be used are CCTV cameras, induction loops, LIDAR, radar, infrared thermal imaging and ultrasonic sensors.

2.3.1. Closed Circuit Television (CCTV)

These are currently in place at many level crossings across Britain and most countries with railways too. They aren’t typically used for automated obstacle detection and more for monitoring traffic, preventing and detecting crime and also to witness any level crossing violations. However, they could be used in conjunction with computer algorithms to determine if an object is present on the track.

Figure 9. CCTV camera monitoring Cromwell Lane level

This could be a cost-effective option since CCTV cameras are already a part of the rail infrastructure. These cameras however, are limited in some capabilities. For example, CCTV cameras rely on it being light to pick up objects, so when it's dark they wouldn't be effective for detection.

2.3.2. LIDAR

LIDAR stands for laser image detection and ranging. It works by sending out and receiving laser pulses that reflect off objects; these reflected laser pulses are used to determine whether or not an object is present on the level crossing. The time taken for the laser pulse to return determines the location of an object. The direction and speed of an object can also be found by the qualities of the reflected pulses (Rail Safety & Standards Board, 2006).

Lidar uses light waves which have a shorter wavelength than radio waves meaning that this method should be able to determine an objects size more accurately than radar. The angle at which the lasers are emitted can be varied to cover a specific area and, unlike radar, background objects such as barriers can usually be masked out during installation so aren't picked up by the detector.

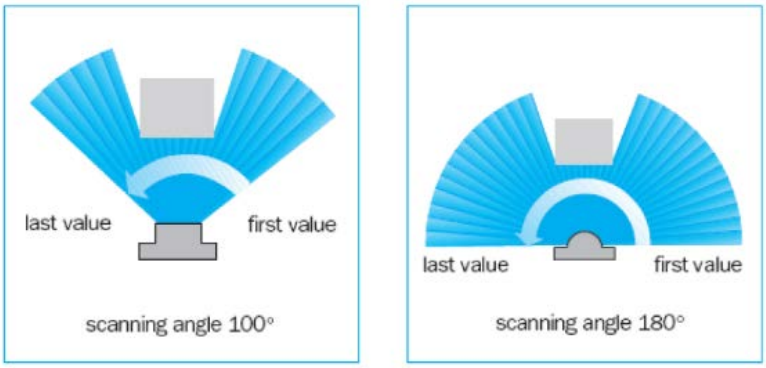

Figure 10. An example of the different scanning angles that LIDAR can achieve (Rail Safety & Standards Board, 2006)

2.3.3. Radar

Radar can be used in two ways to detect objects at a level crossing; the first method involves transmitting radio waves over the detection zone. If an object is present this will produce "echoes" which are received and indicate the presence of something on the crossing. If no echo is received then this will imply that the level crossing is clear. By analysing features of the returned "echo" it is possible to find the speed, distance and location of an object.

Figure 11. A Radar/ LIDAR detctor being used at a level crossing in East Sussex (Rail Engineer, 2015)

The second method of detection involves a radar beam becoming interrupted by the presence of an object. On one side of the crossing, a radar beam would be emitted to a transceiver on the other side, if an object were to interrupt this beam by being in its path; it wouldn't be received by the transceiver indicating the presence of an object. Multiple beams would need to be used to cover the area of a level crossing and more may be needed depending on its size.

2.3.4. Infrared Thermal Imaging

Thermal cameras form an image from infrared radiation, in a similar way in which a CCTV camera uses visible light to form an image. The images are formed from slight temperature differences between objects and can be used at day and night and in all weather conditions unlike CCTV (Figure 12). Thermal cameras would be able to detect if a vehicle has stopped on the level crossing or if anyone is trespassing after the barriers have come down. Unlike other sensors such as LIDAR and radar, a signaller is still able to see with this technology if an object is on the track. This could allow an effective transition from a manned barrier level crossing to a fully-automated one as a human could overlook the system during a trial to see how successful it would be.

Figure 12. An image captured by thermal imaging which shows a clear contrast between pedestrians and vehicles with the background (FLIR,

Infrared thermal cameras have many benefits with respect to level crossings over other methods of detection. They can produce high quality images which, with computer algorithms, can be optimised for automated detection which is a problem with CCTV. Thermal imaging cameras also have the opportunity to have different lenses installed which can enhance the camera view depending on where the level crossing is located and how the camera is mounted.

They are also easy to install, and can be done so on existing infrastructure. In addition to this, infrared thermal imaging cameras are designed for harsh environments and are effective in various climates. With advancing computer technology, thermal imaging cameras can also detect and differentiate between pedestrians and vehicles which could influence what action is needed to be taken if an object is trapped on the level crossing. Some thermal cameras have automated detection already built into them which could be utilised by Network Rail. An issue with thermal imaging is that it would not be able to detect an object the same temperature as the background, such as materials that have fallen from the back of a vehicle. Statistically, the chances of this causing a derailment, damage or injury are very small. This is because the biggest cause of collisions are between the train and vehicles and pedestrians.

2.3.5. Ultrasonic Sensors

These are designed to detect an object by the change in the frequency of sound waves caused by the reflection from the surface of an object. The system emits ultrasonic sound pulses which are above the frequency which can be heard by human ears. When the pulse reaches an object, the surface of the object reflects the sound. In a level crossing application they need to be suspended above the crossing facing down in order to be effective. Multiple ultrasonic sensors would need to be used in order to cover the whole area of the crossing. The sensors would be close to overhead lines meaning that they would generally be difficult to install and maintain. Also, because the sensors would be visible to the public more than other obstacle detection methods, they are more likely to be vandalised.

Ultrasonic sensors are often used in the automotive industry for car parking sensors. Some issues are involved with the use of this type of detection, a build-up of either ice or dirt could restrict the performance and any static objects that are currently on the level crossing like the rails and barriers could also be potentially picked up by the sensors.

2.3.6. Induction Loops

Induction loops consist of a coil transmitter and receiver which are arranged to create an electromagnetic field. When a metallic object enters this field, it disrupts it, and this produces a current which is fed to a processor that determines the size and speed of a metallic object present (Rail Safety & Standards Board, 2006). The nature of this method of detection means that it only detects vehicles and can’t detect pedestrians or other non-metallic objects on the level crossing.

All of these methods of detection could be effective in reducing the risk at level crossings. Using a combination of two of these different techniques would most likely yield the best results as this would make the overall detection more reliable and accurate.

2.4 Obstacle Detection Trails in Other Countries

There are various methods of obstacle detection which have been tested in other countries which could be applied to British railways. However, there are different conditions in these other countries such as pedestrian use and weather. There are also different motivations for introducing obstacle detection to level crossings; these reasons include making trains more efficient and to reduce the costs associated with level crossing signallers and operators.

2.4.1. Germany

Germany first trialled obstacle detection on 70 different level crossings and used radar detectors. Since introducing it, there have been no known instances of objects going undetected, but there were some cases of false positives occurring. The main reason for the German railways to introduce obstacle detection wasn't primarily to improve safety but rather the economic benefits (Rail Safety & Standards Board, 2006). The level crossings upgraded are the equivalent of manual barrier or gated crossings in Britain. Germany also thought that there was an economic preference to replace automatic half barrier crossings with grade separation schemes such as bridges and underpasses where possible.
The overall cost of upgrading each level crossing was approximately €100,000, half of this cost was for the installation and interfacing with existing equipment and the other half was for the cost of equipment, this gave a financial payback of about 2 years (Rail Safety & Standards Board, 2006). The radars were calibrated to detect vehicles, cyclists and "adult-sized" pedestrians but not smaller children and animals. This is because there have been no accidents that have involved small children and ignoring smaller objects means that fewer false positives will occur.

Figure 13. A Radar detector in place at one a German level crossing (ACBahn, 2013)

The barrier lowering sequence activates the radar scanner, if an object is detected then a message is sent to the train alerting the driver that something is on the crossing, so they can take suitable action. If something is found to be on the crossing then the exit barriers are raised to let anything trapped out. Level crossings with obstacle detection require annual maintenance and the expected lifetime of the obstacle detection is approximately 20-25 years (Rail Safety & Standards Board, 2006).

2.4.2. Italy

Italy has used radar obstacle detection at various level crossings, this was mainly done to minimise human error and workload and to also reduce the operating costs. Italy, similarly to other countries, has only focussed to prevent catastrophic events from occurring so the obstacle detection is designed to detect only large objects, such as vehicles. Pedestrians who are on the level crossing when the radar is activated should not intentionally be detected as the minimum detection size has been set at $0.5m^3$ to avoid false positives. There have been some problems reported with the radar, in heavy rain there have been issues with detection and there has been “stability problems of the signal from the antenna of the radar” (Rail Safety & Standards Board, 2006).

2.4.3. The Netherlands

The initial obstacle detection trials in the Netherlands were done at 2 different sites, they were first considered after problems with cars “zigzagging” and road traffic queuing on the crossing. Grade separation schemes were considered but they were seen as a very expensive compared to level crossings, and in some areas there is insufficient space. The trials carried out were to see if obstacle detection could be effective for a quad-gate crossing with skirt; their appearance is similar to that of a British manually controlled barrier with CCTV. The first trial used a combination of radar detection and induction loops between the rails and level crossing barriers. Only vehicles were designed to be detected but some adult sized pedestrians were inadvertently picked up too. The radar detection was activated as the barriers closed, if an object was detected then the entrance barriers would still close but the exit barriers would remain open to provide enough time for the crossing user to exit. After the barriers close, the radar is turned off and obstacle detection is then just carried out by only induction loops. If a vehicle is found to be on the track at this point then the train driver would be signalled and the emergency brakes would be applied.

Originally, the strike-in time for these crossings before being upgraded was 25 seconds and the strike-in point was around 1km. After the upgrade these values were increased to 42 seconds and 1.6km respectively (Rail Safety & Standards Board, 2006). This new system was proven to avoid train-vehicle collisions, but there was a downside to this upgrade. Due to the increase in strike-in time, a number of pedestrians reportedly attempted to go over the barriers, to quickly pass the crossing. These people were detected and caused an approaching train to stop; this caused delays and a potential risk for train passengers due to heavy braking.

Due to these trains being delayed due to braking, another trial was carried out with different criteria. In this second trial there was no communication whatsoever between the detector and the train. Instead, if the obstacle detection showed that there was an object on the track the only action that happened was that the exit barrier is raised. As this detection method doesn’t lead to the train slowing

Figure 14. Netherlands level crossing with radar detection (UIC, 2013)

or stopping, the strike-in time remained the same as it originally was (25 seconds) which was designed to reduce the number of pedestrians crossing when the barriers are lowered.

2.4.4. Sweden

Sweden first introduced obstacle detection in the 1990's to around 100 level crossings. This was primarily done so that the line speeds of the railways could be increased. The obstacle detection Sweden used was induction loops because alternatives were not around at the time. If an object is detected on the level crossing the Swedish system has 2 responses, the first is that the lowering of the exit barriers is limited to 45° to let any trapped vehicle to escape, the second is for the train to brake (Rail Safety & Standards Board, 2006).

Sweden experienced some problems with the introduction of induction loops. Some of them were subject to electromagnetic interference and the vibrations caused by the train also interfered with the detection signal. This was improved by turning off the induction loops once the barriers are fully lowered. The obstacle detection was introduced to high speed lines in Sweden and there haven't been any recorded incidents at those level crossings since. There have, however, been incidences of trains coming to a stop at level crossings, but it isn't known whether these were false positives or actually prevented a collision from happening.

2.4.5. Japan

Over half of all railway accidents that occur in Japan happen at a level crossing. There are approximately 2000 level crossings in Japan and of that number, around 700 have been installed with obstacle detection. They currently use two different types of obstacle detection; induction loops and optical beam sensors, which are the most commonly applied. Japan's attitude towards level crossing safety is to avoid larger collision events such as trains hitting vehicles. Therefore, the detection used is primarily there to detect vehicles and not pedestrians. Optical beam sensors have some issues, they can become unstable in periods of heavy snowfall, they require daily maintenance to get rid of any stains and they often detect pedestrians causing trains to stop.

Japan also looked into other options rather than just obstacle detection to improve the safety of their level crossings. Grade separation schemes such as bridges and underpasses have been considered, there has also be attention given to other safety measures including; emergency buttons for crossing users, improvements to crossing barriers and alarm devices, introducing crossing watchmen and more.

2.4.6. USA

The USA has trialled three different types of obstacle detection for level crossings: they have used laser and video imaging, radar and a combination of infrared and ultrasonic detectors (Rail Safety & Standards Board, 2006).

The laser and video imaging detection was done with a double, infrared, digital camera system which had a high-sensitivity, and a three-dimensional laser scanner used with a high-speed rotating camera. These two devices gather the same information but work independently to improve the reliability of the detection. The combination of these methods meant that there was no disturbance to operations, high resolution was achieved and it had low sensitivity due to weather and damage. This method achieved a 97% success rate for the USA, the failures were due to one missed detection and one false positive.

The radar system used was a single unit and placed on one side of the crossing; the unit emits pulses of radio waves and then "listened" for the echoes from objects. This trial wasn't as much of a success as the first; it couldn't operate dynamically meaning it couldn't detect moving objects. Only 65% of static detections were a success, 24% were false alarms and the rest were missed by the detector (Rail Safety & Standards Board, 2006). The false alarms were caused by pedestrians who were detected close to the crossing but not actually using it.

The last trial of using a combination of passive infrared and ultrasonic detectors was done by suspending the sensors above the crossing pointing downwards towards the tracks. 12 sensors were used in total to improve the accuracy of the results. 98.5% of the results were a success; the only time the detector didn't work effectively was the missed detection of a motorbike (Rail Safety & Standards Board, 2006).

2.5 Current Obstacle Detection used in Britain

Over the last couple of years Network Rail has started to introduce obstacle detection to some British level crossings. Every level crossing which has had obstacle detection included looks like a MCB-CCTV crossing. They have full barriers that extend across and close off the road and footpaths, both 2 full barriers and 4 half barriers have been used in this application. A signaller is still required for these crossings but a traditional CCTV camera has instead been replaced with a combination of both radar and LIDAR sensors. In addition to this, the barriers are also fitted with "skirts" that stop anyone from going under the barriers to get to the other side (Network Rail, 2016).

These new level crossings are called Manually Controlled Barriers with Obstacle Detection (MCB-OD). A signal is shown to the train driver that it is safe to proceed after the crossing has closed and the obstacle detection shows that the crossing is clear. The signaller at these crossings no longer has access to CCTV footage of the crossing or direct observation and must instead rely purely on the LIDAR and radar sensors.

A key feature of the MCB-OD is that the closing sequence of the barriers is automatically initiated when a train hits a predetermined strike-in point. The strike-in point is far back enough so that the train can stop before the protecting signal; which provides the information on whether or not the crossing is clear.

Figure 15. Polegate Crossing, MCB-OD (Rail Engineer, 2015)

Most of the features of the MCB-OD are automated including the lowering, stopping the lowering of the barriers if something is detected, and the raising of the barriers. However, the signaller is still provided with the function to raise and lower the barrier if the obstacle detection shows that an object is on the level crossing. The signaller can raise and lower the barriers until the detection shows that nothing is on the crossing. If the detection keeps showing a positive detection then a team from Network Rail will arrive swiftly to determine what is happening at the crossing.

2.6 Autonomous Trains

An autonomous train means that a driver would not be required for any of the operations of a train to be carried out as normal. Trains are on a fixed track so they would appear to be more suited for autonomy than road vehicles, yet it is in that area where most of the focus is. Autonomous trains are currently used in some applications, for example, the Docklands Light Railway (DLR) is a fully automated train service that runs on the London Underground. This however, is a network that is on highly protected infrastructure and is low speed in comparison to Britain's Mainline Network (Rail Technology Magazine, 2014).

Figure 16. A train on the DLR line on the London Underground (Evening Standard, 2012)

Some rail companies have proposed driverless trains with the intention that they would "avoid conflicts at junctions and allow more frequent services to run on the network" (politics.co.uk, 2017). However, the Rail Drivers' Union has completely disregarded the thought of having autonomous trains on the network and they are adamant that trains will always need to have a driver.

In contrast to this, Deutsche Bahn (German Railways) have said that they want to have introduced long-distance, autonomous trains by 2023 (Hars, 2016). For current autonomous railways, like the DLR, there is very little intelligence on the actual train itself and instead it is the infrastructure and a centralised controller which determines the actions of the train. On long-distance high speed trains though, most of the controls would need to be on the trains themselves as it would be too costly to upgrade hundreds of miles of railway infrastructure. However, it would be beneficial at high risk areas such as level crossings, to have some increased safety measures to reduce the likelihood of an incident.

There are various arguments for and against introducing fully autonomous trains to the entirety of the railway network in Britain. In the year 2015/2016, there were 28 reports of shock and trauma at level crossings, most of which affected train drivers who witnessed accidents or near misses. By replacing the driver with an autonomous system this number would be reduced drastically, as there would be no one to be there to see such incidents happen. A main "advantage of self-driving trains does not lie so much in cost reduction but in the ability to increase network capacity" (Hars, 2016). This is because trains would be able to take more frequent journeys at shorter distances. Another reason why autonomous trains would be beneficial with respect to level crossings is the reduction in reaction time. Currently, if a driver is told of an obstruction on a level crossing they are signalled and told to come to a stop, before the brakes are applied there is the time taken for the driver to react to the situation. Without a driver, this reaction time wouldn't exist, meaning that the strike-in time can be reduced for level crossings. Therefore, they can be closed for a shorter length of time, reducing waiting times for pedestrians and vehicle users.

There are some issues with not having a driver on the train, typically the driver is the front-line mechanic if something goes wrong and has the ability to override the system to ensure that any types of train failures can be overcome (Rail Technology Magazine, 2014). In addition to this, having a driver that is human means that they can adapt to most situations, which an autonomous system would only be able to achieve with very advanced algorithms.

The introduction to autonomous trains is still some years away and in order for it to be a success the infrastructure needs to be designed to accommodate for this, in order to protect people and vehicles (Rail Technology Magazine, 2014). However, autonomous trains could be very beneficial to the introduction of automated obstacle detection at level crossings as they "could significantly lower costs, increase capacity and flexibility" (Hars, 2015). Since long-distance, autonomous trains are more of an idea at the moment for British railways, there could be the inclusion of a feature on a train that causes automatic braking, if the obstacle detection has picked something up on a level crossing. A system like this could even start the transition of Britain's trains from manned to driverless.

3. Potential Solutions

3.1. Chosen Obstacle Detection Method

After evaluating all of the research of obstacle detection it appears that using a combination of infrared thermal cameras and LIDAR sensors would have the most successful result. Radar has seen much success in the past but LIDAR is more accurate due to the shorter wavelength of light; in addition to this it would also be very beneficial to visually monitor the level crossing by using a thermal infrared camera. CCTV would also be possible for this but there are various advantages that thermal cameras have over traditional cameras that are currently used to monitor level crossings. Infrared thermal imaging cameras are unaffected by sun glare, headlights, shadows and can be used during the night as they rely on heat rather than light. In addition to this, computer algorithms can detect objects with a thermal imaging camera much more accurately and reliably than CCTV as there is a greater contrast between vehicles and pedestrians with the background. Some infrared thermal cameras have automated detection software already in place making them even more advantageous over CCTV. The artificial intelligence which monitors these infrared images can become more sophisticated over time without having to replace the actual cameras themselves.

There are limited trials on these methods of detection in other countries but that is because these technologies have only recently become advanced enough to be used in this application. They have had very successful trials in other applications of obstacle detection.

The use of infrared thermal cameras would not only provide detection but unlike LIDAR and radar, which are currently used for obstacle detection by Network Rail, it would also provide video footage of any incidents or misuse that could be later viewed. This would also help with prosecution, if any offences take place, as the thermal camera would be able to see the exact nature of what is happening at the level crossing. This footage could also allow a signaller to still operate the level crossing if the automated system stopped working as they'd be able to see if it was clear or not. Until autonomous trains appear on British railways, a signaller could still do some of the operations, similar to the MCB-OD, but when trains become automated this could become a fully automated system of detection. Thermal imaging cameras can also be acquired for prices a lot lower than the current radar detectors that Network Rail use (Rail Safety & Standards Board, 2006).

Due to issues in other countries with false positives, it is logical to have the obstacle detection set to only pick up on objects that are larger than a small child (over 1 metre). This is due to there not being a single reported incident of a young child who has been alone and been involved with a collision with a train at a level crossing. With recent advancements in thermal technology however, it could be possible to determine what object is actually trapped on the crossing, irrelevant of size.

3.2. Barriers

In order for obstacle detection to be fully effective at level crossings, full barriers that cover the entrance and exit separately must be used instead of a half barrier. One of the main features of an AHB crossing are the short strike-in times, which are a minimum of 27 seconds. If an object was stuck on the crossing the approaching train wouldn't be able to stop in time to avoid a collision if the train was travelling at full speed. The way around this would be to increase the strike-in distance, thus increasing the waiting time for vehicles and pedestrians at the crossing. This would, however, lead to an increase in the misuse of automatic half barrier crossings as more vehicles and pedestrians would "zigzag" over the crossing to avoid waiting; similarly to what happened in the Netherlands' trial.

Figure 17. Left: The current setup at Collingham level crossing (AHB). Right: Edited image showing barriers on both sides of the road for the introduction of obstacle detection

Another problem with introducing obstacle detection at an AHB crossing is that without the addition of full barriers, vehicles and pedestrians could easily cross over after the barriers are down, which could lead to a positive detection and the train would need to brake to avoid an incident. A way to counteract this could be by only having the obstacle detection active for the first few seconds after the barriers are down. If vehicles and pedestrians then decided to pass the crossing, they wouldn't be detected and wouldn't cause the train to stop. However, this could still lead to a collision so it would be most advantageous for any level crossing with obstacle detection to have full barriers. Having the obstacle detection active for the first few seconds with full barriers would also be more beneficial rather than leaving it on the whole time the barriers are down. It would reduce the number of false positive readings due to people jumping over the barriers and would still pick up objects that are trapped on the crossing.

Automatic half barrier crossings have had the most fatalities for vehicle occupants at level crossings so it seems more feasible to upgrade these crossings to full barriers, as this alone could reduce the number of fatalities at level crossings across Britain. Also, the maximum speed a train can travel through an AHB crossing is 100mph but for a crossing with full barriers, a train could go through at 125mph. Therefore, trains could be more efficient as they would be able to reach their destination faster and so could run more frequently. However, this can only be applied to cases where the level crossing is the constraint on line speed.

3.3. Level Crossings to Upgrade

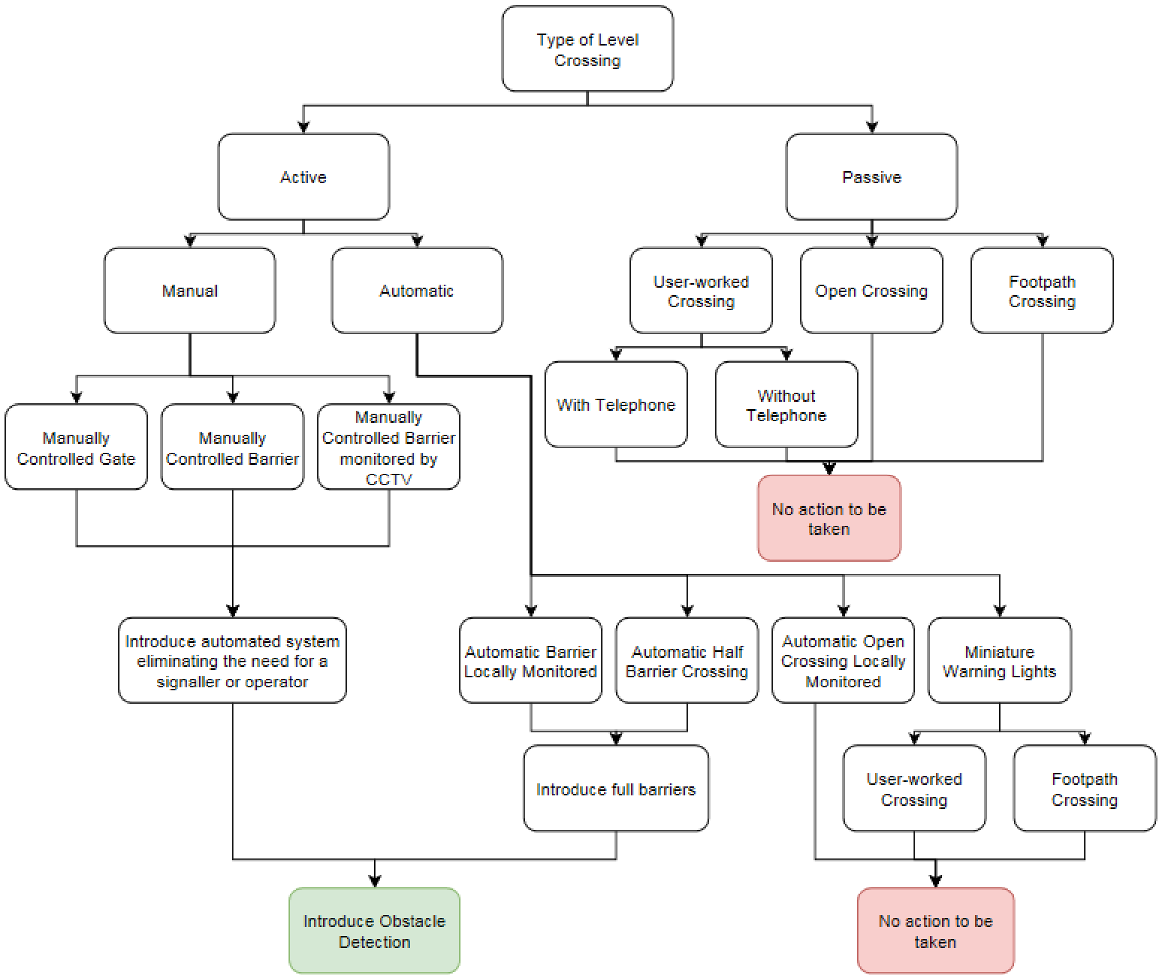

Figure 18. A flowchart to show a generic outline of what should happen at each current type of level crossing

Figure 18 shows which level crossings would ideally be upgraded to level crossings that have full-barriers and have obstacle detection implemented. Every AHB and ABCL crossing should be upgraded to have full barriers as this alone should reduce the risk associated with using them.

Having obstacle detection implemented at manned barriers and gates may not necessarily improve the safety of them, but it would reduce the operating costs as members of staff wouldn't be required to use the barriers. In some instances though, it would be logical to close many of these manned gates and barriers down. For example, Grassthorpe Lane is a manned gate level crossing with a crossing keeper, it has an average of 8 vehicles and 3 pedestrians a day use it. There are various other locations within a mile of this level crossing that would allow pedestrians and vehicles to cross such as MCB-CCTV crossings and bridges. By removing manned gate crossings that are rarely used (under 30 vehicles a day) and replacing the rest with full-barrier crossings with automated obstacle detection, should see a large reduction in cost over time for Network Rail who has to employ staff to manually operate these crossings. Also, manned gates can only be used during set times during the day when a member of staff is there to operate the crossing for users, so by either replacing them or eliminating them would give road users and pedestrians more freedom to cross the railway.

Footpath, user worked and open crossings would be left alone for the introduction of obstacle detection. This is because of the lack of use of most of these crossings; many footpath crossings in Britain are only used by 1 pedestrian a day and the benefits of upgrading these aren't worth the large costs. In numerous places there are also many space constraints and barriers simply would not fit where many footpath crossings are.

Open crossings would have sufficient space to include full barriers, but for the amount they're used it doesn't appear feasible to have obstacle detection. Each day, on average, an open crossing is used by approximately 147 vehicles and 30 pedestrians which may suggest obstacle detection could be suitable. However, there are an average of 7 trains a day using open crossings and over 50% of open crossings have fewer than 5 trains pass them every day. In addition to this, there are low line speeds of 10mph at open crossings; therefore these crossings should not have obstacle detection equipped as the chances of a collision are very small.

Which Level Crossings should be upgraded to include obstacle detection?			
Introduce Obstacle Detection		**Leave**	
Type of Crossing	**Number**	**Type of Crossing**	**Number**
Automatic Barrier Locally Monitored	124	Automatic Open Crossing Locally Monitored	31
Automatic Half Barrier	434	Footpath Crossing	2571
Manually Controlled Barrier	181	Footpath Crossing with Miniature Warning Lights	88
Manually Controlled Barrier monitored by CCTV	514	Open Crossing	46
Manually Controlled Gate	128	User worked Crossing with Miniature Warning Lights	104
		User worked Crossing with Telephone	1727
		User worked Crossing without Telephone	463
Total	**1381**	Total	**5030**

Table 3. An approximation of the level crossings which should and should not be upgraded to have automated obstacle detection

Approximately 1400 level crossings under this criteria could be effectively upgraded to have obstacle detection (Table 3). This number of 1381 level crossings would vary though, depending on individual circumstances at each of the level crossing sites.

Although obstacle detection would be an effective way to mitigate the risk at level crossings, it would still be safer to replace crossings with grade separation schemes, if possible. With cost-benefit analysis, this method provides the best reduction in risk against cost; therefore this is a desirable project for Network Rail to keep pursuing.

4. Evaluation of Potential Solutions

4.1. Timings (Initial Stages after Strike-in point)

Scenario 1: No obstacle detected:

The first situation that could occur is the most ideal situation, this would be when the level crossing barriers are down and the obstacle detection would not pick up an object on the crossing. This would, in turn, relay a message to the train saying it is clear to pass and can continue at the normal speed. The longest that this should take would be approximately an additional 24 seconds, meaning that the total time from the start of the closure sequence to the train reaching the crossing would be about 54 seconds.

Stage Number	Description	Time Taken (s)
1	*Train hits the strike-in point continuing at full speed*	0
2	*Amber Warning Lights & sound*	3
3	*Red Warning Lights & sound*	4-6
4	*Barriers on the left-hand side of the road (entrance) descend to the lowered position*	6-8
5	*Remaining barriers then lower*	8-10
6	*Obstacle Detection on the crossing*	3
7	*Scenario 1, 2 or 3*	~

Table 4. The initial stages in what will happen when the train approaches a level crossing

Scenario 2: Primary detection:

In this scenario, the initial obstacle detection in the last stage of Table 4 would come up with a positive reading indicating the presence of an object on the crossing. In this case, the exit barriers would open simultaneously with a signal being relayed to the train to apply the brakes. The exit barriers would be up for 3 seconds to allow whatever is trapped inside to have an opportunity to escape. The exit barriers would then lower again, and the obstacle detection would once again be activated. If the obstacle detection shows that nothing is on the track then the train can accelerate after its reduction in speed before the level crossing. This leads to a maximum additional closing time of approximately 41 seconds so the train would reach the crossing within 71 seconds of the activation of the closure sequence.

Scenario 3: Primary and Secondary detection:

After the barriers are down, the obstacle detection would give a positive result meaning the train should apply the brakes and the exit barriers would open to allow any trapped object out. After the barriers have been up for 3 seconds they will then close and obstacle detection will be activated once again. If this detection shows another positive result, this will relay a message to the train to come to a full stop before the crossing. The time taken in this scenario, from the initiation of the closure sequence of the level crossing, to when the train comes to a full stop before the crossing is approximately 77 seconds. The most similar type of crossing to the type proposed is a manually controlled barrier, which has an average closure time around 227 seconds so these calculated values are a large improvement.

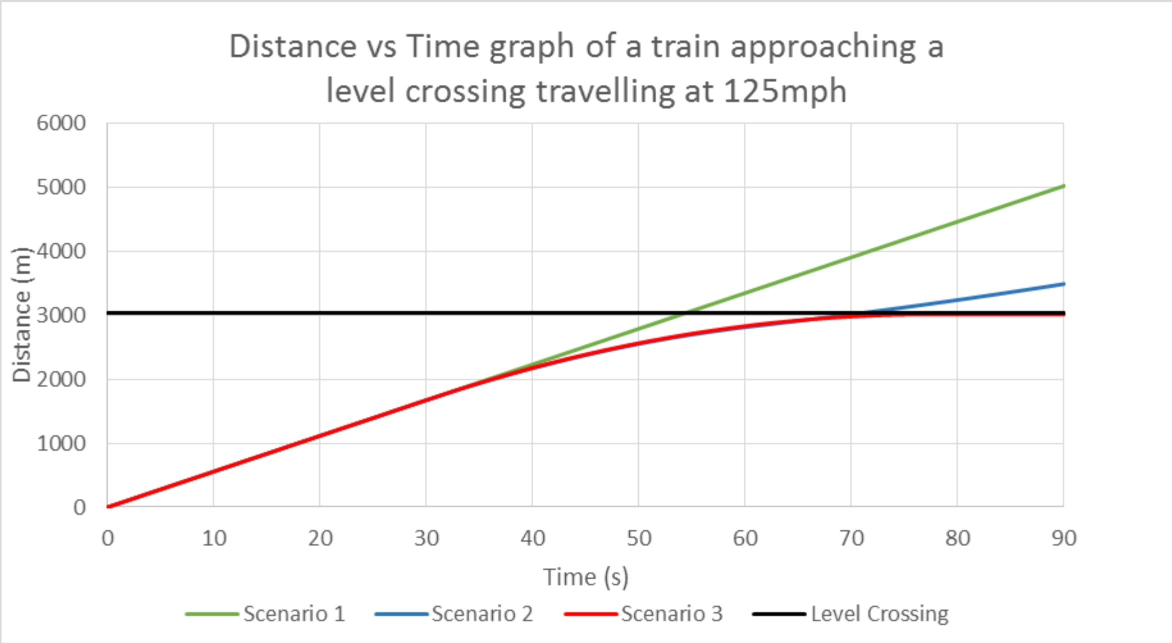

Figure 18. A graph showing the nature of a train travelling 125mph after it hits the strike-in point of a level crossing

Figure 18 shows the speed of a train, originally travelling at 125mph, experiencing the three scenarios previously mentioned. In each case, the speed of the train is identical up until 30 seconds, as this is the maximum time from when the amber warning lights activate to the barriers closing and the obstacle detection taking place. The black line which is just above 3000m is the distance from the strike-in point to the level crossing itself. The gradient of the lines correspond to the speed that the train is travelling. It can be seen that in 'Scenario 3', the gradient of the line becomes smaller and reaches zero just under the black line meaning the train has stopped before the crossing. An estimation of the arrival times for varying speeds of train can be seen in Appendix E.
This is only an approximation of times; there are many factors that could influence the time taken for the train to reach the crossing. This includes the weather and the weight of the train. The value used for deceleration was also an estimate and will vary for different types of trains.

4.2. Strike-in Distance

The strike-in distances were calculated from the time it would take a train to come to a full stop 50m from the level crossing, which is a requirement stated from the ORR (Office of Rail Regulation, 2011). The maximum strike-in distance that would be enforced would be just over 3000m from the level crossing site. This should enable enough time for the barriers to lower and obstacle detection to activate, then from there, the time taken for the train to come to a full stop before reaching the level crossing. The value of deceleration used for the train was 12% of acceleration due to gravity (approximately 1.1892m/s²) which is used as a general principle. However, the effects of leaves on the line can reduce this figure, so areas around level crossings should be a priority for vegetation clearance.
The speed reduction to a third of the train's original speed was done as this gives sufficient time for the train to reach this speed as the second cycle of obstacle detection is being completed. Rather than

have a specified distance from each level crossing to initiate the closure sequence of the crossing, it should be dependant of the speed of the train approaching instead. This would be more effective with an automated train as it would be able to determine the precise time for the closure sequence to start rather than having a driver who wouldn't be able to react as quickly.

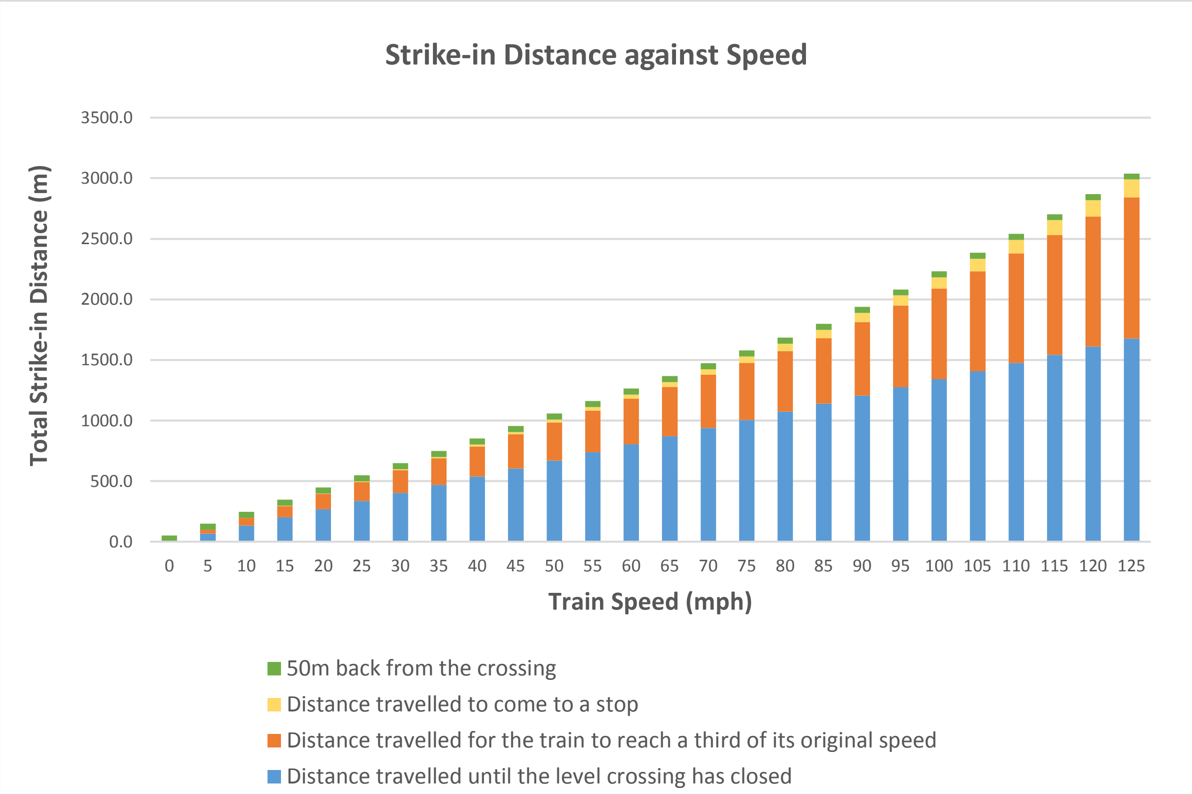

Figure 19. The strike-in distances of the different speeds a train could travel through a level crossing

There is a linear relationship between the strike-in distance and the train speed up to 80mph (Figure 19) . This is because, at 80mph and lower, a train can sufficiently reach a third of its original speed during the time it takes the barriers to reopen and close (approximately 21 seconds). For trains faster than 80mph, the time it takes to reduce their speed to a third is longer than 21 seconds. Therefore, the distance it takes to reach this reduction in speed, increase as the train gets faster.

5. Conclusion

This study has demonstrated that the combination of methods involving thermal imaging, LIDAR and full barriers would provide a safe transition from current level crossings to an automated level crossing that wouldn't require a signaller to control the barriers.

In some circumstances, introducing obstacle detection would not be sufficient to stop a collision from happening; suicide is a prime example of this. For this to happen someone could simply jump over the barriers as a train was approaching and the train would not be able to stop in time. However, for people who may have fallen on the crossing or for vehicles that are stuck, automated obstacle detection would be very effective in reducing the chances of a collision.

In order for obstacle detection to be effectively introduced and incorporated to level crossings with the suggested method, it must be done so with full barriers. Having half barriers would result in greater risk and potential injury to passengers as heavy braking would be a more regular occurrence by trains, due to an increase in detections with vehicles and pedestrians zigzagging.
Automated trains won't become a common mode of transport on British railways for years to come, therefore having a means of visually observing a level crossing as well as this acting as obstacle detection seems to be the best way forward for the current British railways.

6. Further Work

As a future work it'd be to interest to test this proposed system on a level crossing in a controlled environment. The system should be set up to be completely automated but should be monitored through the infrared thermal camera to see the effectiveness of the system. Various sized objects should pass over the level crossing varying from smaller animals, adult-sized pedestrians to large road vehicles. The system would ideally filter out smaller animals to hopefully reduce the number of false positives that occur.
In addition to this testing, the cost of upgrading level crossings should be another area, which is looked into further. There are no figures online for how much it would cost to upgrade different types of level crossing. This is most likely because every level crossing is slightly different in some way and each one would cost a different value to upgrade. There are also limited figures available for the cost of obstacle detection. Upgrading a MCB-CCTV level crossing would cost the least as the barrier equipment is already in place, unlike an AHB crossing.

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8. Appendix

Appendix A. List of MCB-OD level crossings in Britain

Level Crossings with obstacle detection						
Number	Name	Individual Risk	Collective Risk	Line Speed (mph)	Number of Trains	Usage per day
1	Allens West	J	4	45	71	5535 vehicles, 351 pedestrians or cyclists
2	Aslockton	J	6	75	54	1242 vehicles, 108 pedestrians or cyclists
3	Attleborough	I	4	90	65	6561 vehicles, 529 pedestrians or cyclists
4	Auckley	J	6	75	29	1688 vehicles, 162 pedestrians or cyclists
5	Balderton	F	8	125	229	5 vehicles, 1 pedestrians or cyclists
6	Balne	F	7	125	151	27 vehicles, 14 pedestrians or cyclists
7	Balne Lowgate	F	7	125	151	27 vehicles, 14 pedestrians or cyclists
8	Berwick	H	4	90	142	4131 vehicles, 216 pedestrians or cyclists
9	Billingshurst	F	3	60	120	2282 vehicles, 999 pedestrians or cyclists
10	Bingham	J	5	75	65	5454 vehicles, 162 pedestrians or cyclists
11	Blankney	J	6	75	49	4887 vehicles, 122 pedestrians or cyclists
12	Blue Gowt	I	8	75	28	95 vehicles, 27 pedestrians or cyclists
13	Brandon	J	4	90	65	11176 vehicles, 178 pedestrians or cyclists
14	Brewery Lane	H	8	75	23	26 vehicles, 18 pedestrians or cyclists
15	Brierfield	J	6	50	37	2755 vehicles, 250 pedestrians or cyclists
16	Broad Oak	E	4	60	53	215 vehicles, 39 pedestrians or cyclists
17	Burn Lane	I	8	75	29	108 vehicles, 27 pedestrians or cyclists
18	Cheal Road	J	9	75	23	56 vehicles, 6 pedestrians or cyclists
19	Church Lane	I	9	75	18	20 vehicles, 6 pedestrians or cyclists
20	Dean	I	6	85	77	567 vehicles, 27 pedestrians or cyclists
21	Dean Hill	J	6	85	77	1188 vehicles, 27 pedestrians or cyclists
22	Eccles road	I	6	90	70	1754 vehicles, 89 pedestrians or cyclists
23	Fenwick	F	7	125	151	33 vehicles, 11 pedestrians or cyclists
24	Fish Dock Road	J	5	25	72	3971 vehicles, 223 pedestrians or cyclists
25	Flax Mill	H	7	75	33	68 vehicles, 35 pedestrians or cyclists
26	Folly Bank	J	6	75	28	2241 vehicles, 149 pedestrians or cyclists
27	Four Lane Ends	G	6	70	63	324 vehicles, 135 pedestrians or cyclists
28	Garden Street	F	3	15	72	2436 vehicles, 3092 pedestrians or cyclists
29	Golden High Hedges	L	12	75	18	27 vehicles
30	Gosberton	J	7	75	23	1134 vehicles, 54 pedestrians or cyclists
31	Green Lane	F	3	60	50	3456 vehicles, 108 pedestrians or cyclists
32	Harling Road	I	5	75	71	3375 vehicles, 108 pedestrians or cyclists
33	Henwick Hall	J	8	75	29	216 vehicles, 27 pedestrians or cyclists
34	Heyworth	F	6	125	156	18 vehicles, 17 pedestrians or cyclists
35	Holme	G	4	125	293	1482 vehicles, 47 pedestrians or cyclists
36	Huncoat	I	5	70	102	1690 vehicles, 113 pedestrians or cyclists
37	Kesteven	J	6	60	73	2241 vehicles, 14 pedestrians or cyclists
38	Kingsknowe	D	2	70	131	1377 vehicles, 122 pedestrians or cyclists
39	Kirknewton	I	4	95	115	4147 vehicles, 247 pedestrians or cyclists
40	Lakenheath	J	6	75	70	4762 vehicles, 30 pedestrians or cyclists
41	Littleworth	K	6	75	30	7560 vehicles, 27 pedestrians or cyclists
42	Llanelli East	G	3	75	85	6210 vehicles, 1431 pedestrians or cyclists
43	Llanelli West	F	3	75	79	540 vehicles, 1323 pedestrians or cyclists
44	Moss	H	5	125	151	2606 vehicles, 14 pedestrians or cyclists
45	Nantwich	H	3	60	62	9234 vehicles, 2781 pedestrians or cyclists
46	North Carr	K	10	75	24	81 vehicles
47	Orston Lane	I	6	75	58	783 vehicles, 135 pedestrians or cyclists
48	Pevensey	I	4	70	110	5616 vehicles, 162 pedestrians or cyclists
49	Plumpton	I	6	90	78	918 vehicles, 54 pedestrians or cyclists
50	Polegate	F	2	90	148	7128 vehicles, 2889 pedestrians or cyclists
51	Prees	J	8	90	62	324 vehicles
52	Pulford	E	4	60	39	729 vehicles
53	Rowston	I	8	75	49	81 vehicles, 14 pedestrians or cyclists
54	Sandhill Lane	H	6	70	105	501 vehicles, 100 pedestrians or cyclists
55	Saxilby	G	6	65	73	297 vehicles, 135 pedestrians or cyclists
56	Scopwick	J	6	75	49	2478 vehicles, 23 pedestrians or cyclists
57	Shippea Hill	I	6	90	65	2160 vehicles, 81 pedestrians or cyclists
58	Sleaford North	J	9	55	49	162 vehicles
59	Smithy Bridge	H	4	70	153	4104 vehicles, 324 pedestrians or cyclists
60	Spooner Row	I	6	75	70	2011 vehicles, 65 pedestrians or cyclists
61	St James Deeping	K	7	75	28	1368 vehicles, 22 pedestrians or cyclists
62	Sykes Lane	F	6	65	73	59 vehicles, 108 pedestrians or cyclists
63	Thorpe Gates	I	5	90	105	3321 vehicles, 81 pedestrians or cyclists
64	Thorpe Hall	I	5	90	108	2444 vehicles, 128 pedestrians or cyclists
65	Tinsley	L	12	75	28	20 vehicles
66	Ulceby	I	5	40	173	2529 vehicles, 77 pedestrians or cyclists
67	Wallsend	J	4	70	110	8505 vehicles, 189 pedestrians or cyclists
68	Water Drove	I	8	75	23	47 vehicles, 12 pedestrians or cyclists
69	Wellowgate	F	2	15	72	2257 vehicles, 5222 pedestrians or cyclists
70	Wem	H	4	100	71	3672 vehicles, 621 pedestrians or cyclists
71	Wrenbury	I	6	90	62	783 vehicles, 81 pedestrians or cyclists

Appendix B. Spreadsheet of Individual and Collective Risk

		INDIVIDUAL RISK LETTER AND COLLECTIVE RISK NUMBER															
		A	B	C	D	E	F	G	H	I	J	K	L	M	TOTAL		
Type of Level Crossing	**Type of Risk**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**		Sum	**Average Risk**
Automatic Barrier Crossing	Individual	0	0	0	20	30	30	17	10	4	4	2	2	3	122	770	**F**
	Collective	0	12	8	52	19	21	2	6	1	0	0	0	1	122	561	**5**
Automatic Half Barrier Crossing	Individual	0	0	20	186	137	55	15	10	7	3	1	0	0	434	2108	**E**
	Collective	9	102	76	147	45	50	4	1	0	0	0	0	0	434	1590	**4**
Automatic Open Crossing	Individual	0	0	0	7	4	1	4	2	2	3	0	3	4	30	234	**H**
	Collective	0	2	2	3	10	8	1	1	0	1	0	0	2	30	171	**6**
Footpath Crossing	Individual	0	13	1310	1090	52	51	0	3	0	0	0	0	47	2566	9517	**D**
	Collective	2	38	50	307	195	581	278	269	120	424	181	74	47	2566	18825	**7**
Footpath Crossing with Miniature Stop Lights	Individual	0	0	33	48	1	2	1	0	0	0	0	0	2	87	341	**D**
	Collective	0	2	7	24	8	28	7	5	0	3	1	0	2	87	485	**6**
Manned Barrier Crossing	Individual	0	0	0	0	8	20	49	43	24	17	10	9	1	181	1464	**H**
	Collective	0	19	16	49	27	54	6	5	1	2	1	0	1	181	876	**5**
Manned Barrier Crossing monitored by CCTV	Individual	0	0	0	7	24	57	114	90	104	82	23	7	0	508	4101	**H**
	Collective	6	41	54	134	72	139	23	25	6	3	1	3	1	508	2485	**5**
Manned Gates	Individual	0	0	0	2	6	17	22	29	23	6	10	7	3	125	1026	**H**
	Collective	0	1	2	12	17	28	14	32	8	6	2	2	1	125	854	**7**
Open Crossing	Individual	0	0	4	7	4	6	4	3	5	1	1	2	5	42	303	**G**
	Collective	0	2	2	10	7	10	2	5	2	1	0	0	1	42	240	**6**
User-worked Crossing	Individual	22	126	169	68	12	6	1	0	0	0	0	12	46	462	1898	**D**
	Collective	2	3	6	61	17	93	30	97	46	39	11	15	42	462	3550	**8**
User-worked Crossing with Miniature Stop Lights	Individual	2	52	37	9	1	1	0	0	0	0	0	0	2	104	290	**C**
	Collective	2	8	11	39	13	12	4	7	1	4	0	1	2	104	515	**5**
User-worked Crossing with telephone	Individual	24	404	850	366	18	2	3	2	0	0	0	2	50	1721	5659	**C**
	Collective	1	13	24	185	131	358	151	330	191	246	18	23	50	1721	12642	**7**

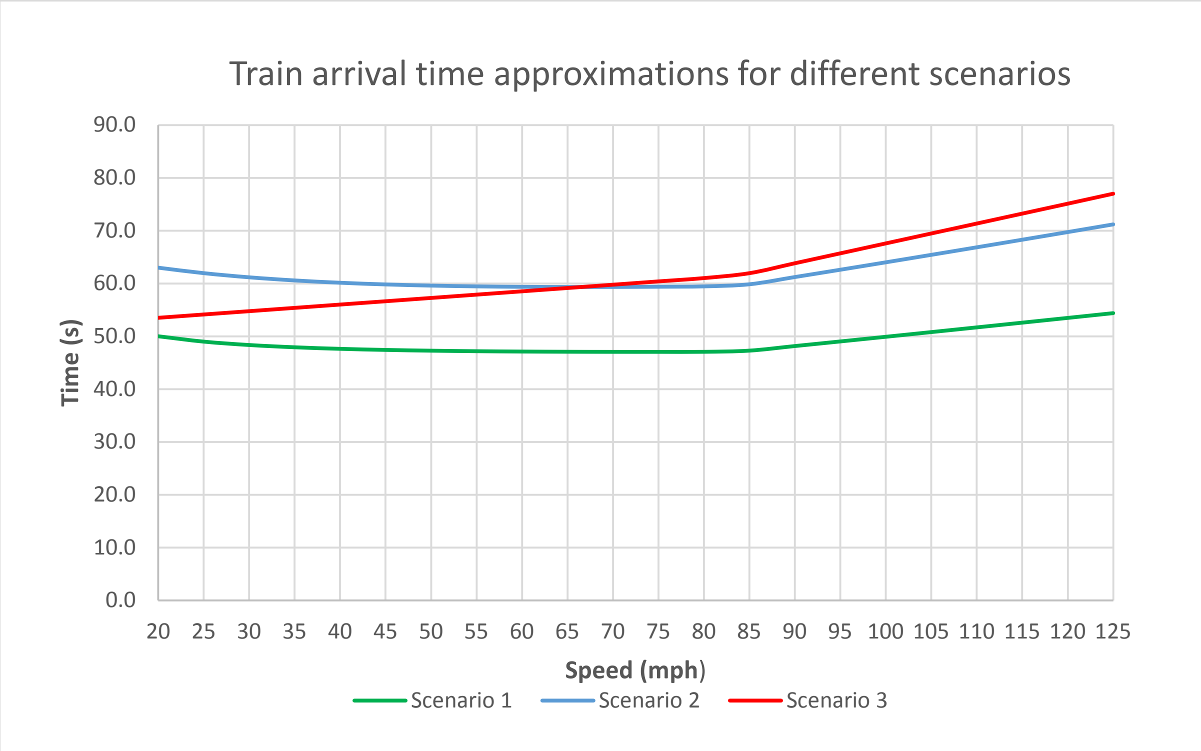
Appendix C. Network Rail Level Crossing Closure List

Network Rail Level Crossing Closure List

Route	Level Crossing Name	Crossing	ELR	Mil	Chai	Level Crossing Right	Closure Solution	Current Project
Anglia	Northumberland Park	CCTV	BGK	6	77	Public	New Footbridge - Ramped	Awaiting Legal Closure
Anglia	TWAO Project	Multiple	N/A	N/A	N/A	Various	Various	Awaiting Legal Closure
Anglia	Gipsy Lane FPG	FPG	LTN1	77	64	Public	Diversion	Consultation
LNE	Haydon Bridge	FPW	NEC2	28	51	Public	New Footbridge - Stepped	Awaiting Legal Closure
LNE	Kirkham Abbey Foot	FPS	YMS	15	3	Public	Diversion	Awaiting Legal Closure
LNE	Hipperholme	FP	MRB	33	50	Public	Diversion	Consents
LNE	Little Bowden	FPmwl	SPC3	82	33	Public	New Footbridge - Stepped	Consents
LNE	Manston	UWCM	HUL4	14	77	Public	Diversion	Consents
LNE	Manston	FPWM	HUL4	14	77	Public	Diversion	Consents
LNE	Abbotts Ripton	FPGT	ECM1	62	60	Public	Diversion	Consultation
LNE	Barretts Lane No 1	FPW	TSN	121	61	Public	Diversion	Consultation
LNE	Blue House	FP	LEN3	92	50	Public	Diversion	Consultation
LNE	Branston Footpath	FP	DBP1	12	39	Public	Diversion	Consultation
LNE	Hough Lane	FPGT	ECM1	115	1	Public	Diversion	Consultation
LNE	Kings Mill No 1	FPGT	PBS2	139	21	Public	New Footbridge - Ramped	Consultation
LNE	Long Lane	FPK	TSN	122	6	Public	New Footbridge - Ramped	Consultation
LNE	Mountsorrel	FPG	SPC5	108	15	Public	Diversion	Consultation
LNE	Nature Reserve	FPGt	TSN	122	46	Public	New Footbridge - Ramped	Consultation
LNE	Whitehouse Lane	FPmwl	ECM1	120	40	Public	Diversion	Consultation
LNE	Ferry Boat Lane	FPW	PED5	16	30	Public	New Footbridge - Ramped	Pre Feasibility
LNW	Dobroyd	FP	MVN2	18	70	Public	New Footbridge - Stepped	Awaiting Legal Closure
LNW	Lime Kiln	FP	NBS	0	12	Public	New Footbridge - Stepped	Awaiting Legal Closure
LNW	Pleasington Golf No.1	UWCT	FHR	6	74	Private	New Footbridge - Stepped	Awaiting Legal Closure
LNW	Stone Station	FP	CMD2	27	8	Public	Diversion	Consents
LNW	Cotton Mill Lane	FP	WSA	6	19	Public	New Footbridge - Ramped	Consultation
LNW	Fisherman's Path Fp	FP	HXS3	12	46	Public	New Footbridge - Stepped	Consultation
LNW	Playing Fields West	FP	FHR	2	49	Public	New Footbridge - Stepped	Implementation
Scotland	Tofthill 1	UWCt	SCM5	15	74	Private	Deed Release	Awaiting Legal Closure
Scotland	Cornton 1 AHB	AHB	SCM3	120	9	Public	Road Bridge	Consents
Scotland	Cornton 2 MSL FP	FPmwl	SCM3	119	59	Public	Diversion	Consents
Scotland	Dalcross AHB	AHB	ANI3	137	17	Public	Diversion	Consents
Scotland	St Ninians	FPmwl	SCM3	117	10	Public	New Footbridge - Ramped	Consents
Scotland	Panholes	FP	SCM4	132	75	Public	New Footbridge - Stepped	Consultation
South East	Glebe Way	FP	VIR	58	35	Public	New Footbridge - Stepped	Consents
South East	Pilgrims Way	FP	SBJ	24	14	Public	New Footbridge - Stepped	Consents
South East	Stone	MGH	HDR	19	14	Public	Diversion	Consents
South East	Stone Crossing	FP	HDR	19	14	Public	New Footbridge - Ramped	Consents
South East	Tidemills Footpath	FP	STS	57	38	Public	New Footbridge - Ramped	Consents
South East	Willingdon Trees	FPS	KJE3	2	73	Public	New Footbridge - Stepped	Consents
South East	Dean Farm	FP	VTB3	22	77	Public	New Footbridge - Stepped	Consultation
South East	Mill Bridge No 1	FP	ATH	71	53	Public	Underbridge	Consultation
South East	Mill Bridge No 2	FP	ATH	71	54	Public	Underbridge	Consultation
South East	Race Course (waiting for funding increase approval	FP	HGG1	26	28	Public	New Footbridge - Stepped	Consultation
South East	Ham Street	FP	ATH	61	51	Public	Station Change	Implementation
South East	Tovil	FP	PWS1	44	30	Public	New Footbridge - Ramped	Implementation
Wales	Cefen Suran	UWC	CWL2	23	6	Private	Deed Release	Consultation
Wales	Caetwpa	UWC	SBA2	63	13	Private	Deed Release	Implementation
Wales	Clawdd Coed UWC	UWC	SBA	61	10	Private	Road Bridge	Implementation
Wales	Pikins FP	FP	SBA	60	35	Public	Road Bridge	Implementation
Wales	Pikins UWC	UWCt	SBA	60	35	Private	Road Bridge	Implementation
Wales	Raullt FP	FP	SBA	60	78	Public	Road Bridge	Implementation
Wales	Raullt UWC	UWCt	SBA	60	78	Private	Road Bridge	Implementation
Wales	Tyddyn-y-pwll UWC	UWCt	SBA	60	50	Private	Road Bridge	Implementation
Wales	Ystrad Fawr FP	FP	SBA	61	25	Public	Road Bridge	Implementation
Wales	Ystrad Fawr UWC	UWCt	SBA	61	25	Private	Road Bridge	Implementation
Wessex	Buriton	FP	WPH1	57	27	Public	Severance	Consents

Appendix D. Lincoln High Street level crossing images

Appendix E. Graph of train approximated arrival times



For Scenario 3, the time taken to stop is a distance of 50m back from the level crossing. For Scenario 1 and 2, it is the time taken for the train to reach the level crossing. At lower speeds this distance of 50m is quite significant because it is the reason why Scenario 3 has a lower arrival time than Scenario 2.